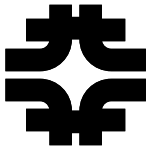


Fermilab

J. MacLachlan, BD/AI

Thursday 25 Sept. 03

Accelerating Lumpy Bunches Through Transition

- bunches observed to be ragged early in cycle (Yang)
- lumpiness causes higher peak currents for given emittance
- strength of most collective instabilities directly proportional to peak current
- Booster already close to NMI threshold for smooth bunches

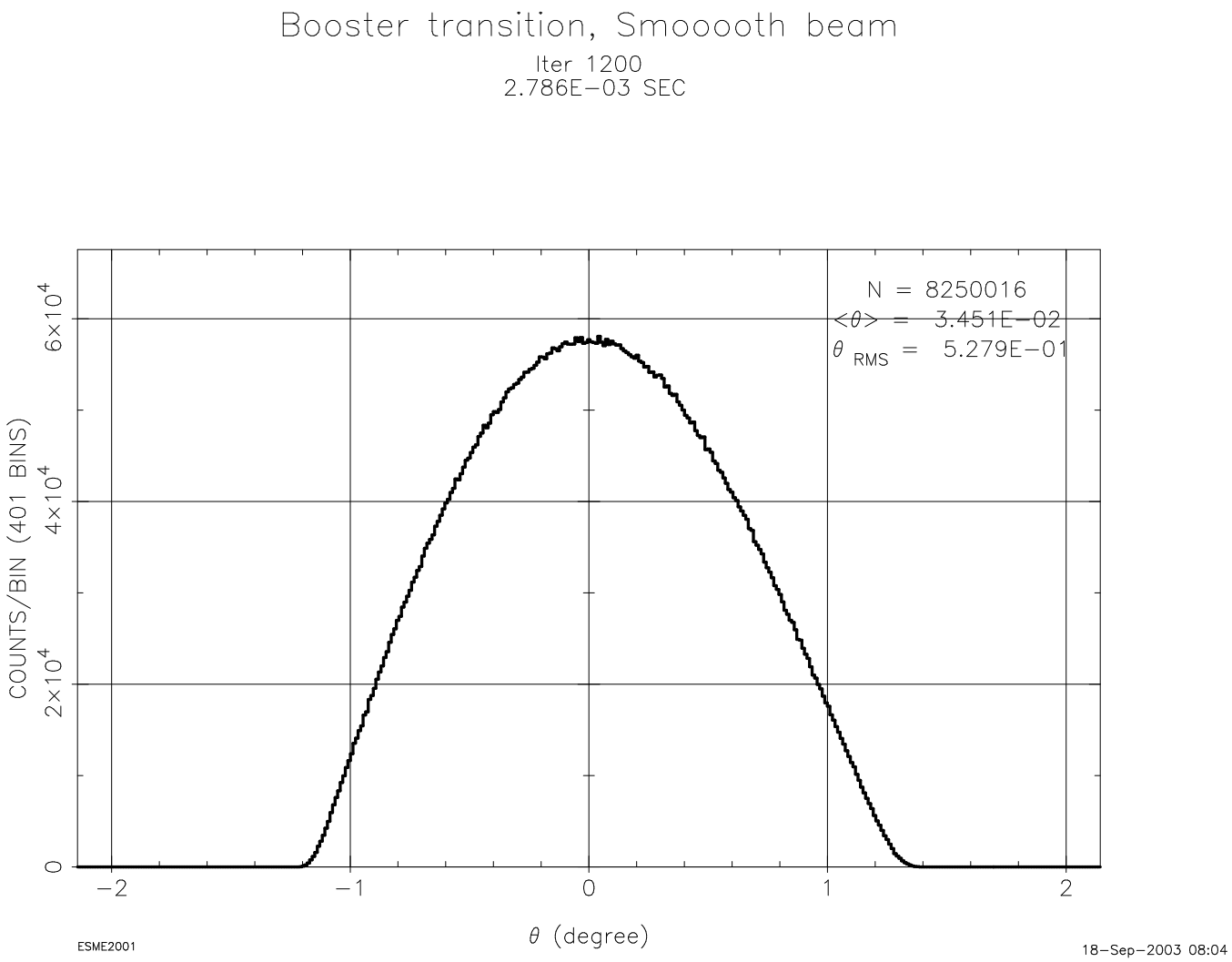
- γ_T jump may be good enough to avoid NMI problem (work in progress)
- A respectable high-brightness injector synchrotron would have a functioning γ_T jump system.

Booster Parameters by guess and by gosh

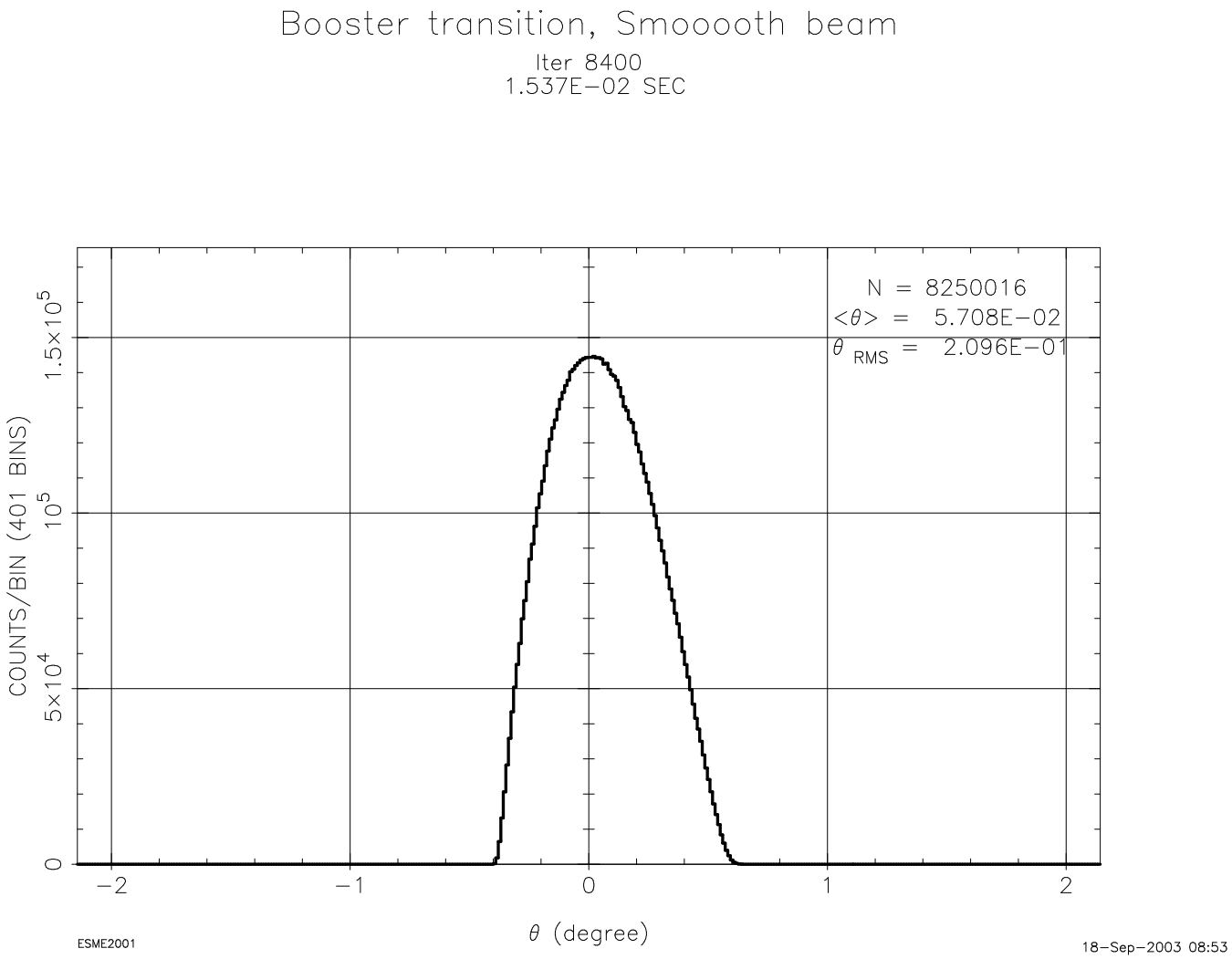
ring radius	75.47	m
injection energy (kinetic)	400.	MeV
extraction energy	8.0	GeV
γ_T	5.446	
ε_ℓ, initial	0.0947	eVs
harmonic number	84	
max. rf volts	1.2	MV
rf frequency	37.9 – 52.8	MHz
sinusoidal ramp	15	Hz
maximum $\dot{p}$	374	GeV/c/s
number of protons	$5 \cdot 10^{12}$	

Transition Parameters analysis

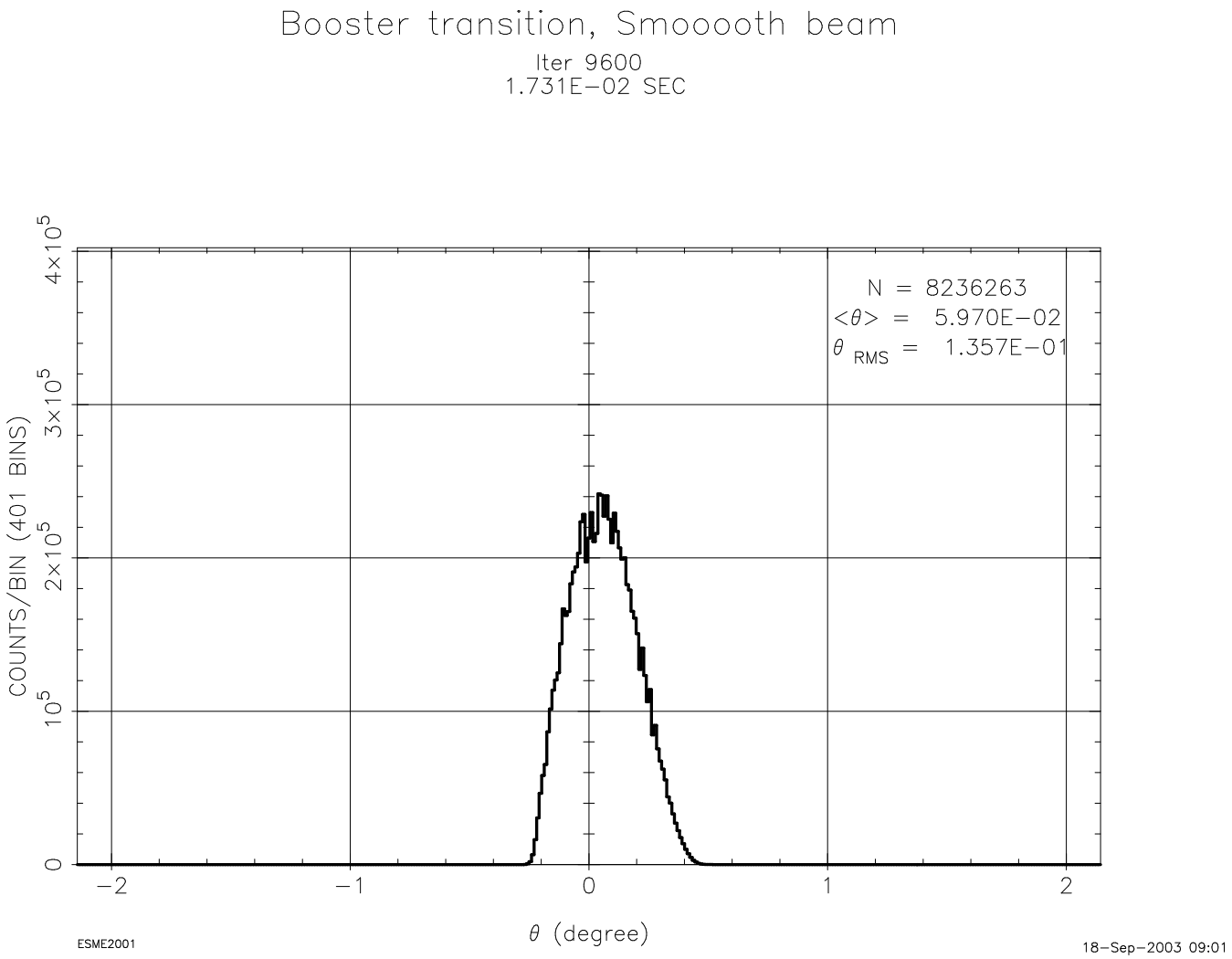
γ_T	5.446	
$\dot{\gamma}$	419.2	s^{-1}
α_1 (ESME)	0.0	
rf amplitude	690.	kV
bunch area	0.0947	eVs
particles/bunch	$6 \cdot 10^{10}$	
harmonic number	84	
Transition energy	5.110	GeV
v/c at transition	0.9829	
rf frequency	52.20	MHz
circulation period	1.609	μs
$\dot{E}$	393.3	GeV/s
ϕ_s	1.161	rad
rms bunch length	0.5445	ns
geometric factor	4.515	
nonadiabatic time	0.2572	ms
nonlinear time	43.30	μs
$\eta_\circ(0)$ (Sorrenssen)	0.5107	
harmonic for $g_\circ/2$	23708	
fastest mode	13688	
“worst” mode	7903	
NMI threshold param.	1.372	
appx. peak current	6.696	A
$\lvert Z_\parallel \rvert$	29.19	Ω
$\frac{\Delta\varepsilon}{\varepsilon}$ (Jie Wei)	0.1280	



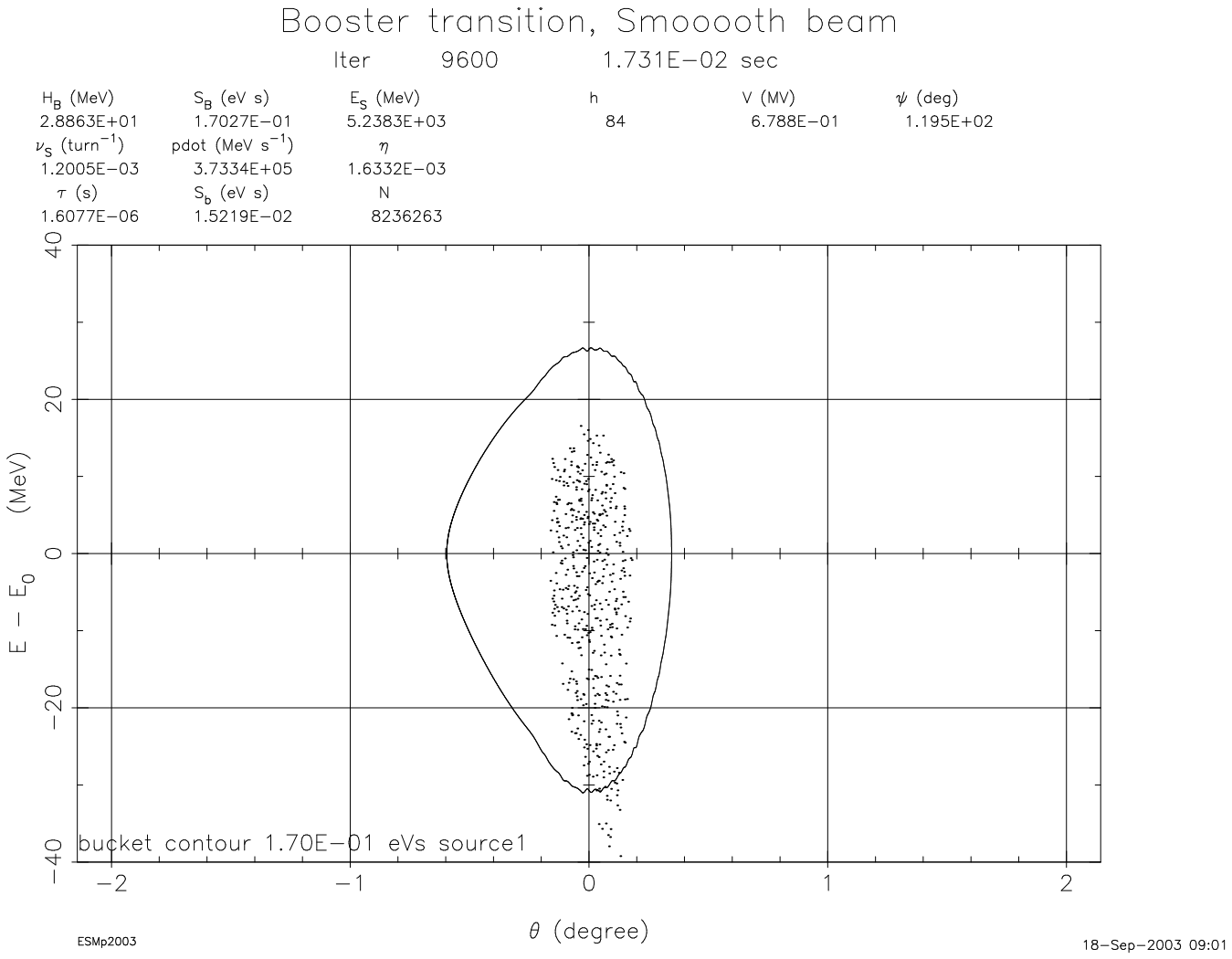
charge profile for smooth bunch of 0.0947 eVs with $6 \cdot 10^{10}$ protons using 8.25 M macroparticles early in Booster cycle



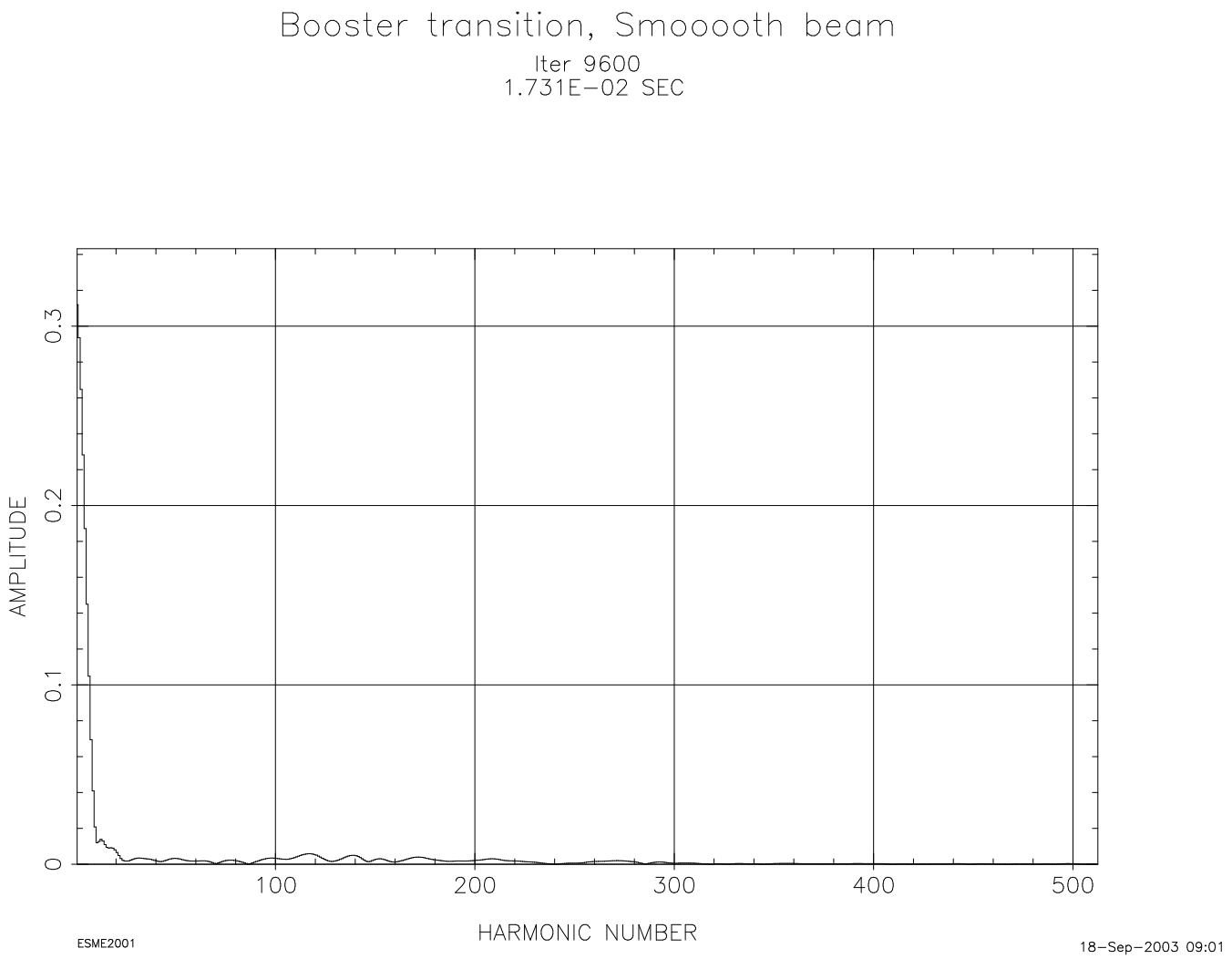
as above at 15.4 ms into cycle



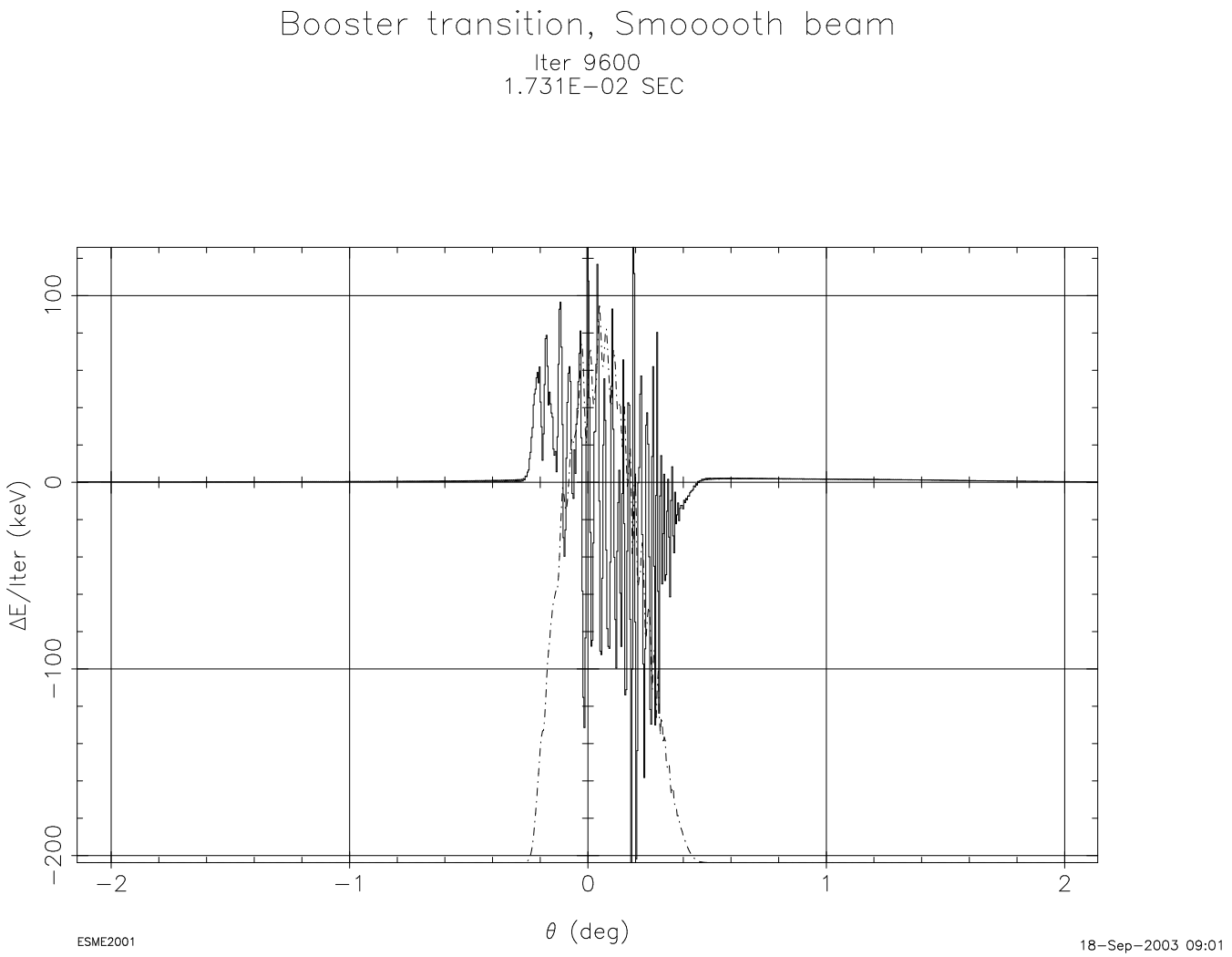
same as above at 17.3 ms — just after transition



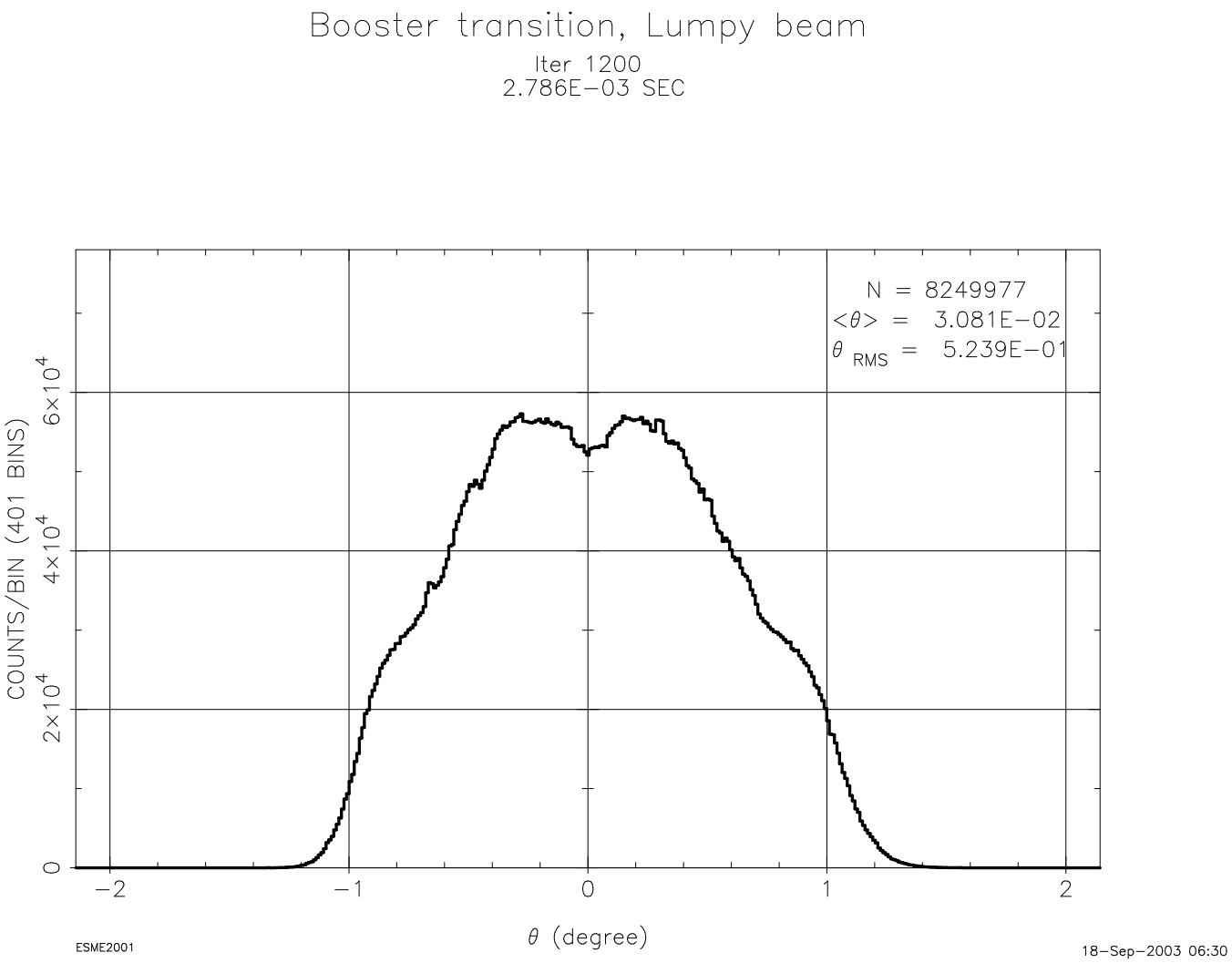
a few of 8.25 m phase space points just after transition — evidence of high collective voltage noticeable on contour. Notice nonlinear single-particle problem(s).



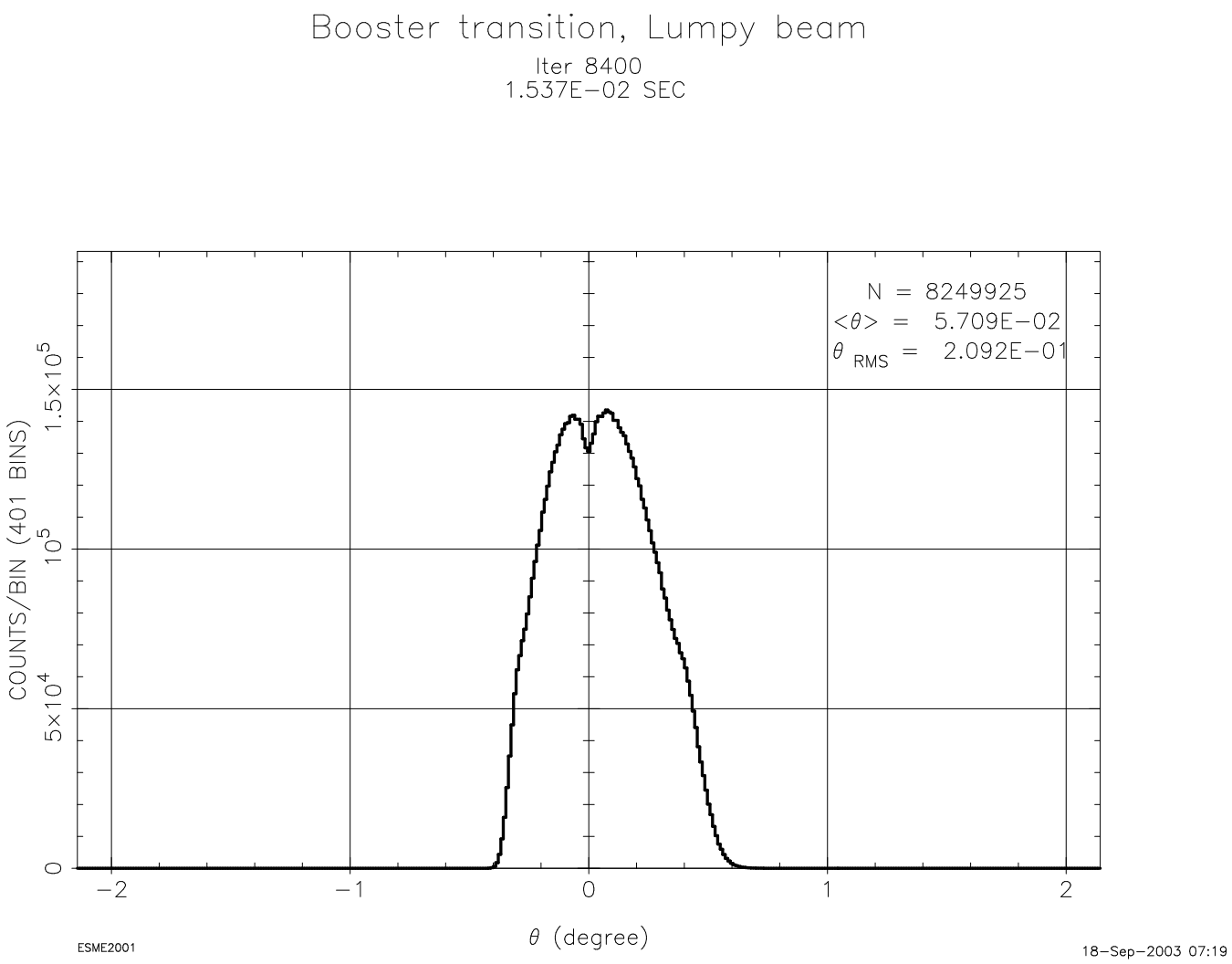
the Fourier spectrum of the beam current just after transition — most excitation below 15 GHz



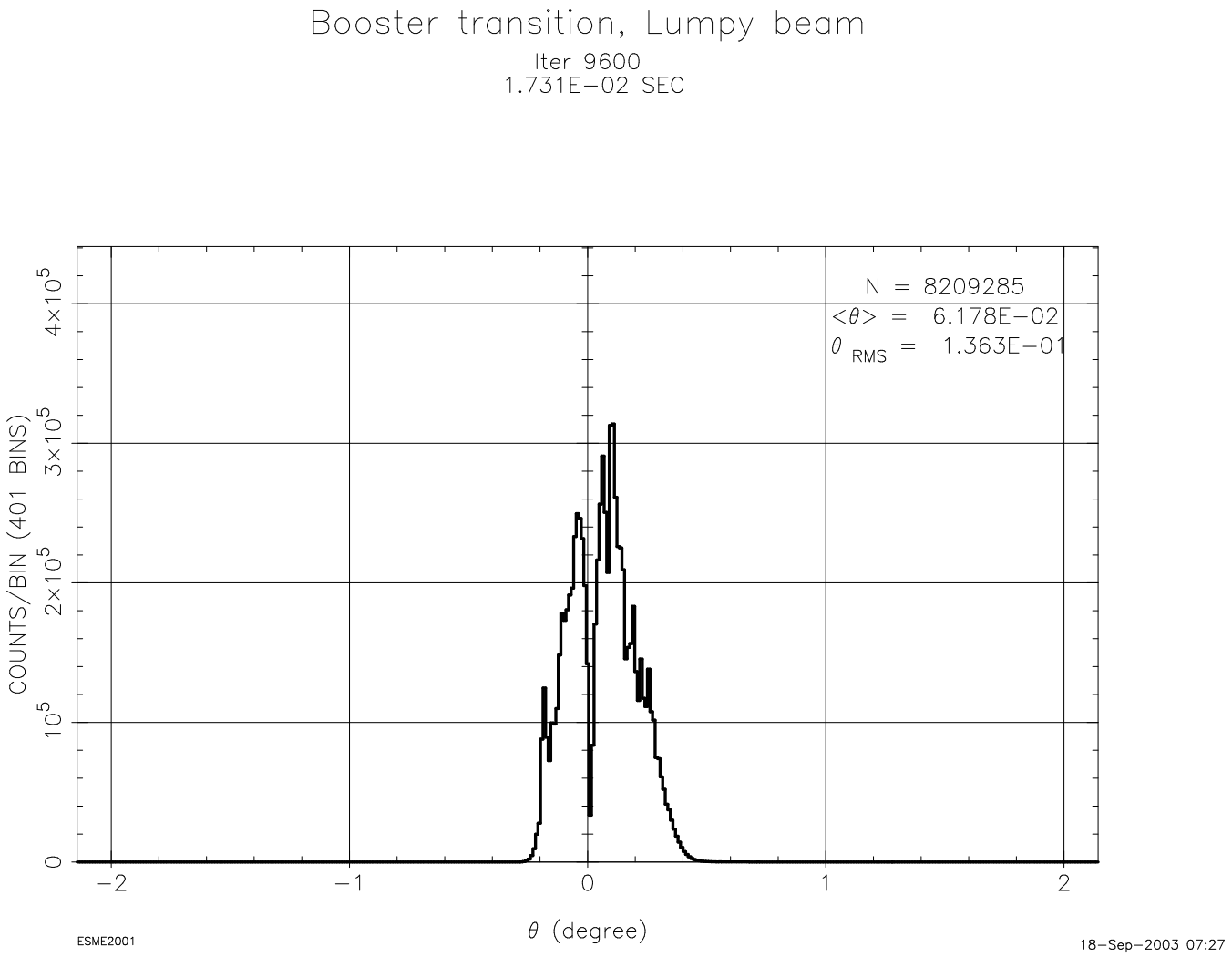
the collective voltage resulting from the previous beam current spectrum — enough to perturb distribution noticeably



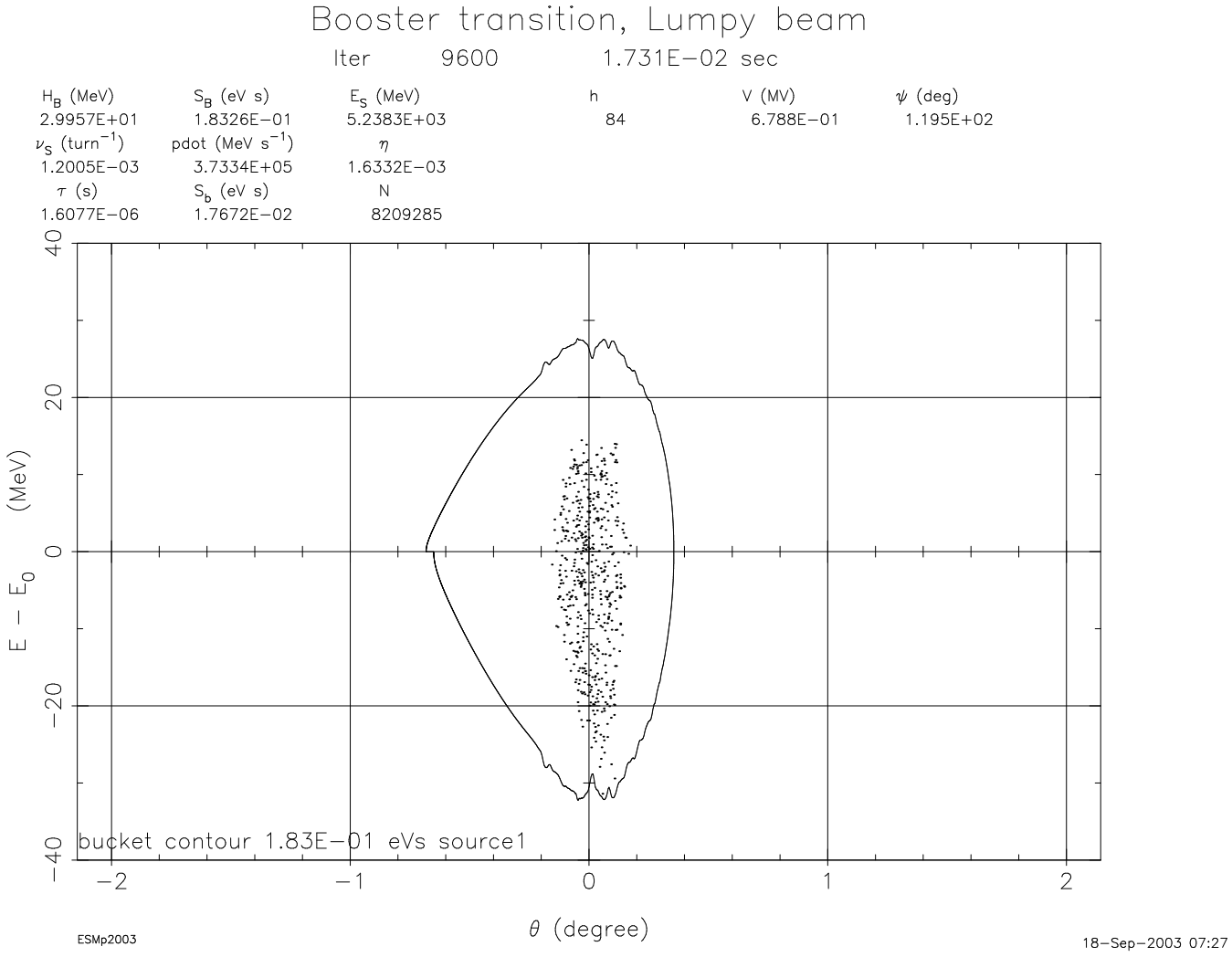
charge profile for lumpy bunch of 0.0947 eVs with $6 \cdot 10^{10}$ protons using 8.25 M macroparticles early in Booster cycle



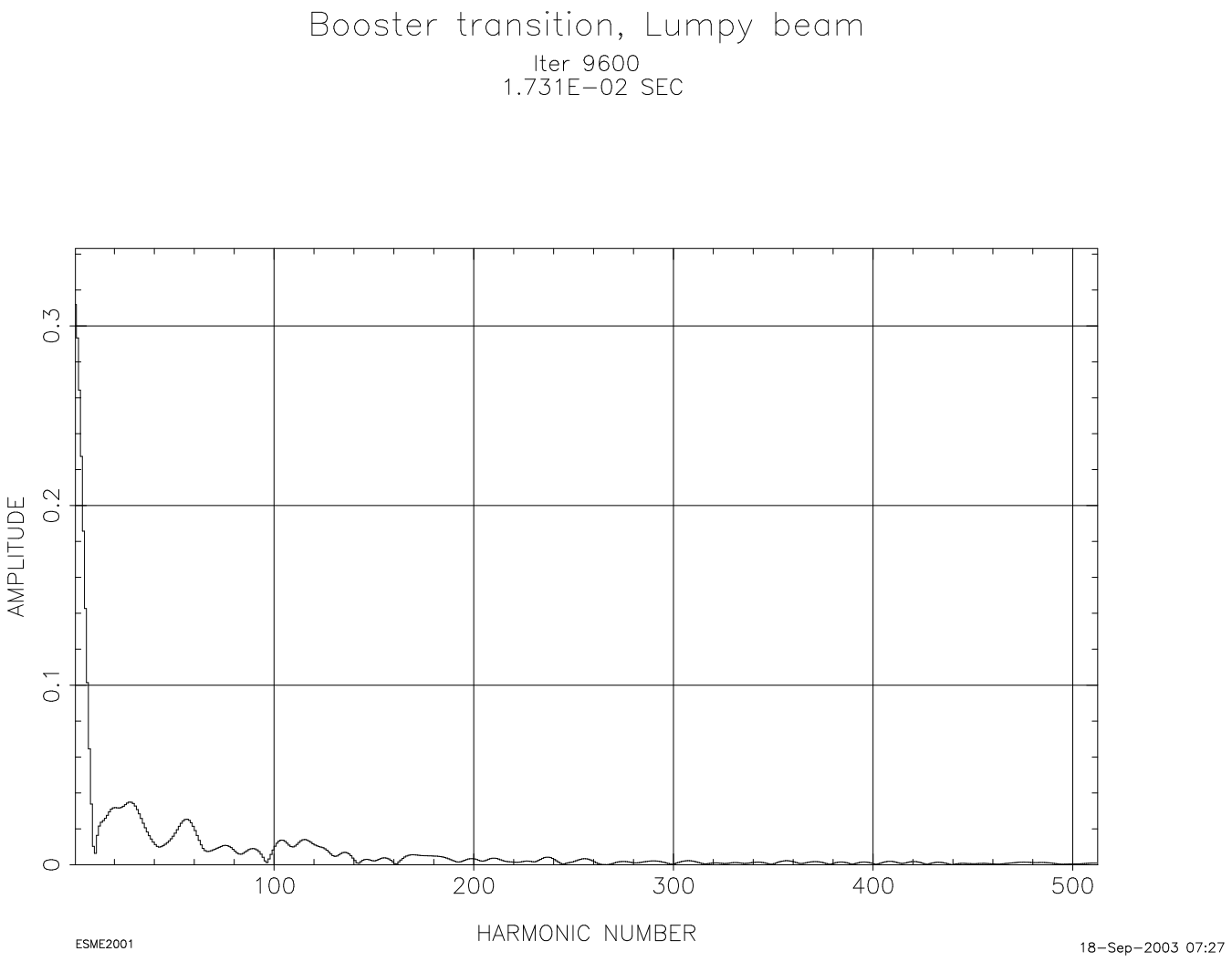
as above at 15.4 ms into cycle



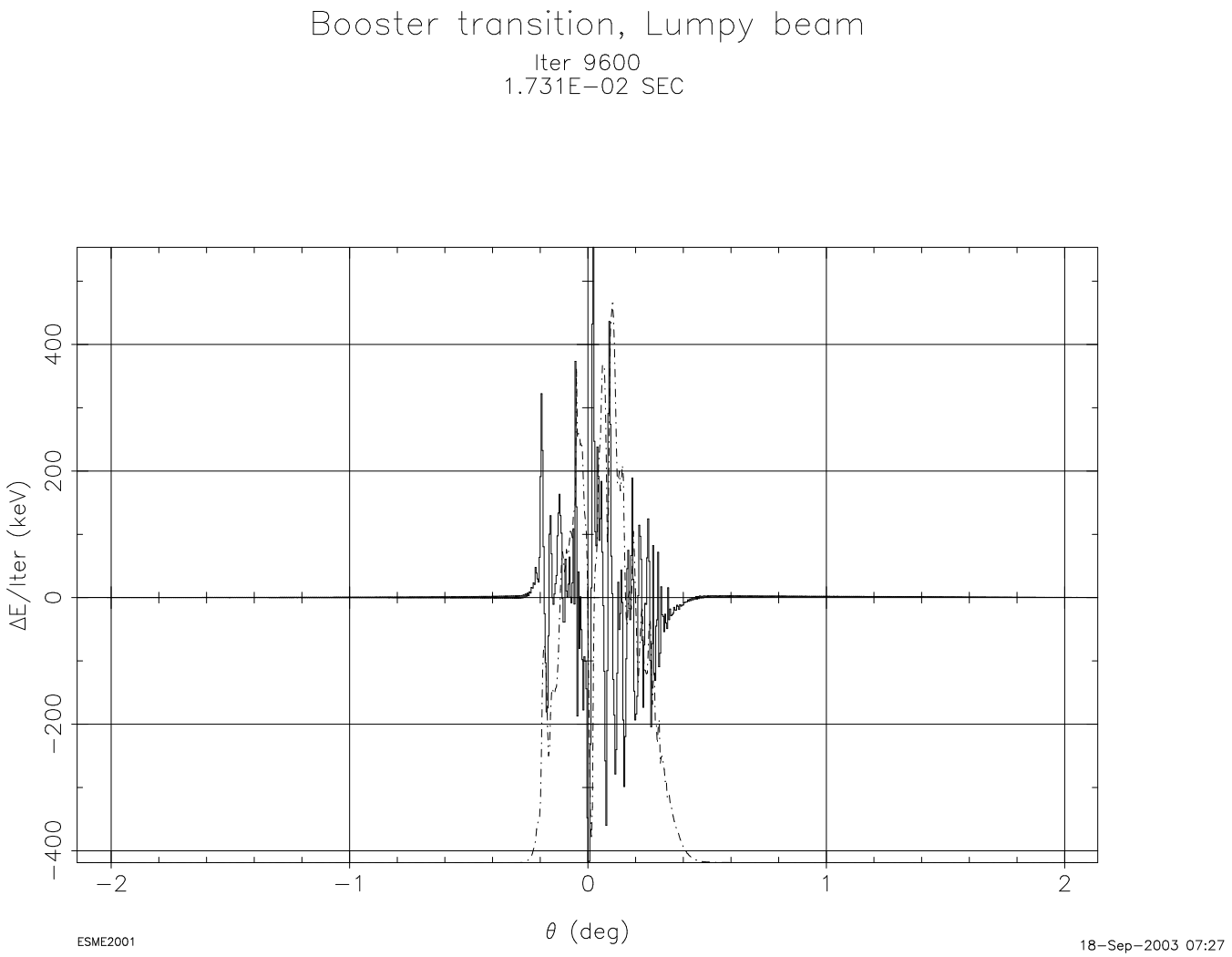
same as above at 1.73 ms — just after transition



a few of 8.25 m phase space points just after transition — marked evidence of high collective voltage on contour. Notice nonlinear single-particle problem(s) also.



the Fourier spectrum of the beam current of the lumpy bunch just after transition — most excitation below 15 GHz, but extending higher at detectable levels



the collective voltage resulting from the lumpy bunch current spectrum — enough to perturb distribution noticeably

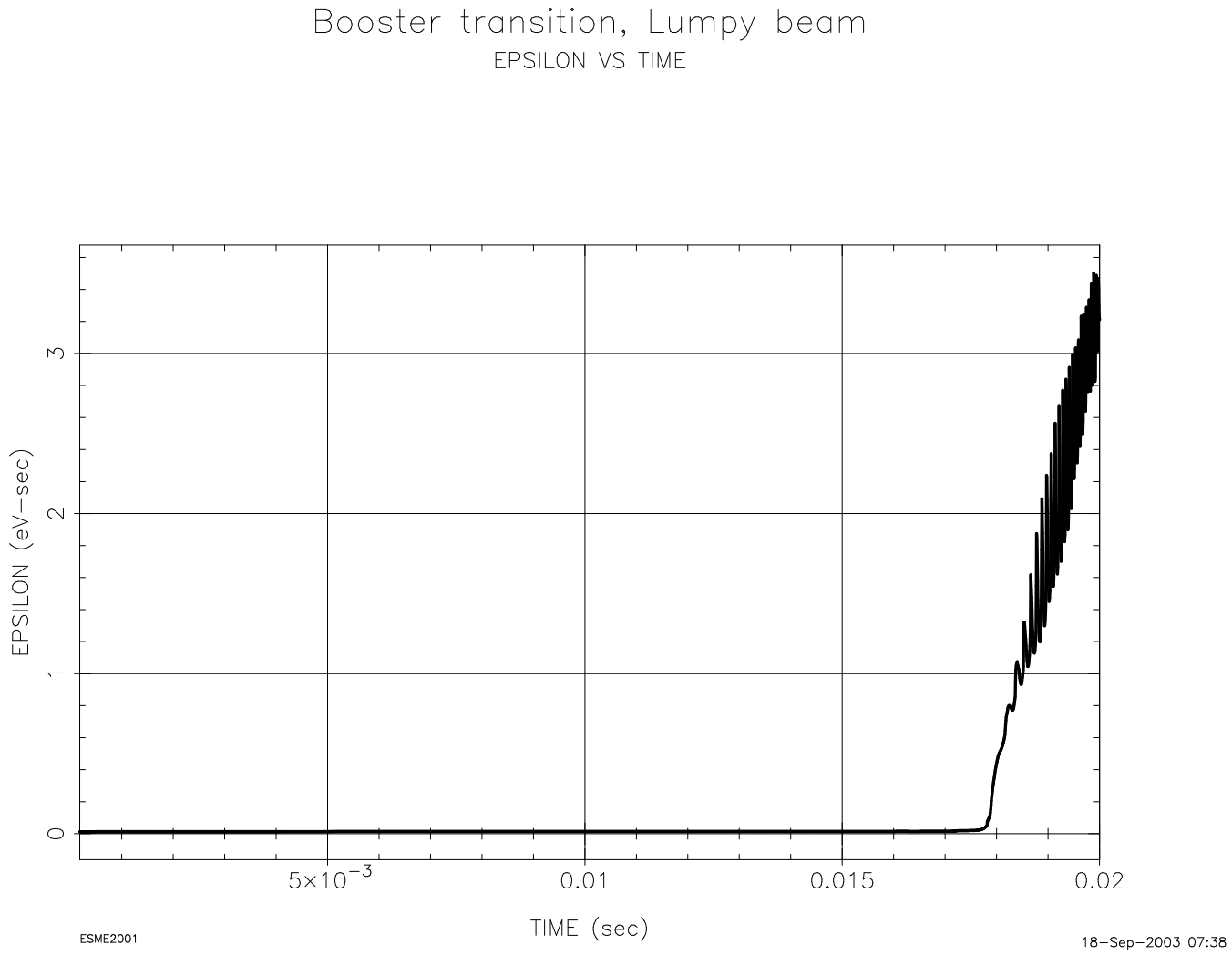
Summary and extrapolation

- Ragged bunch profiles obtained by Lucas are in qualitative agreement with observations of Yang.
- The details of injection do matter much later in the cycle.
- Negative Mass Instability is a relevent problem for near term.
- The γ_T jump deserves respectful attention.

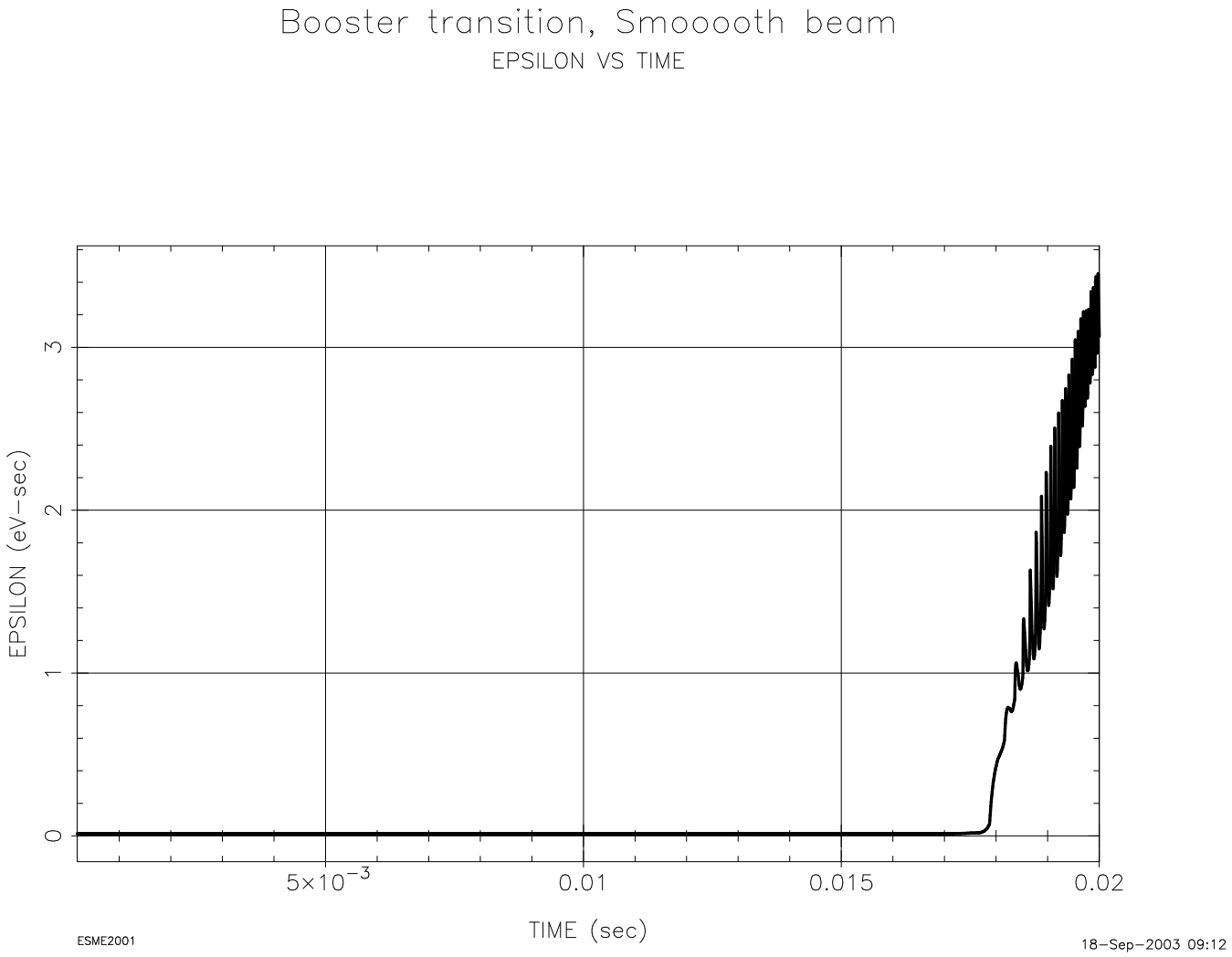
Acknowledgement: Thank you Peter Lucas for a beautifully lumpy distribution.

Addendum 16 October 2003

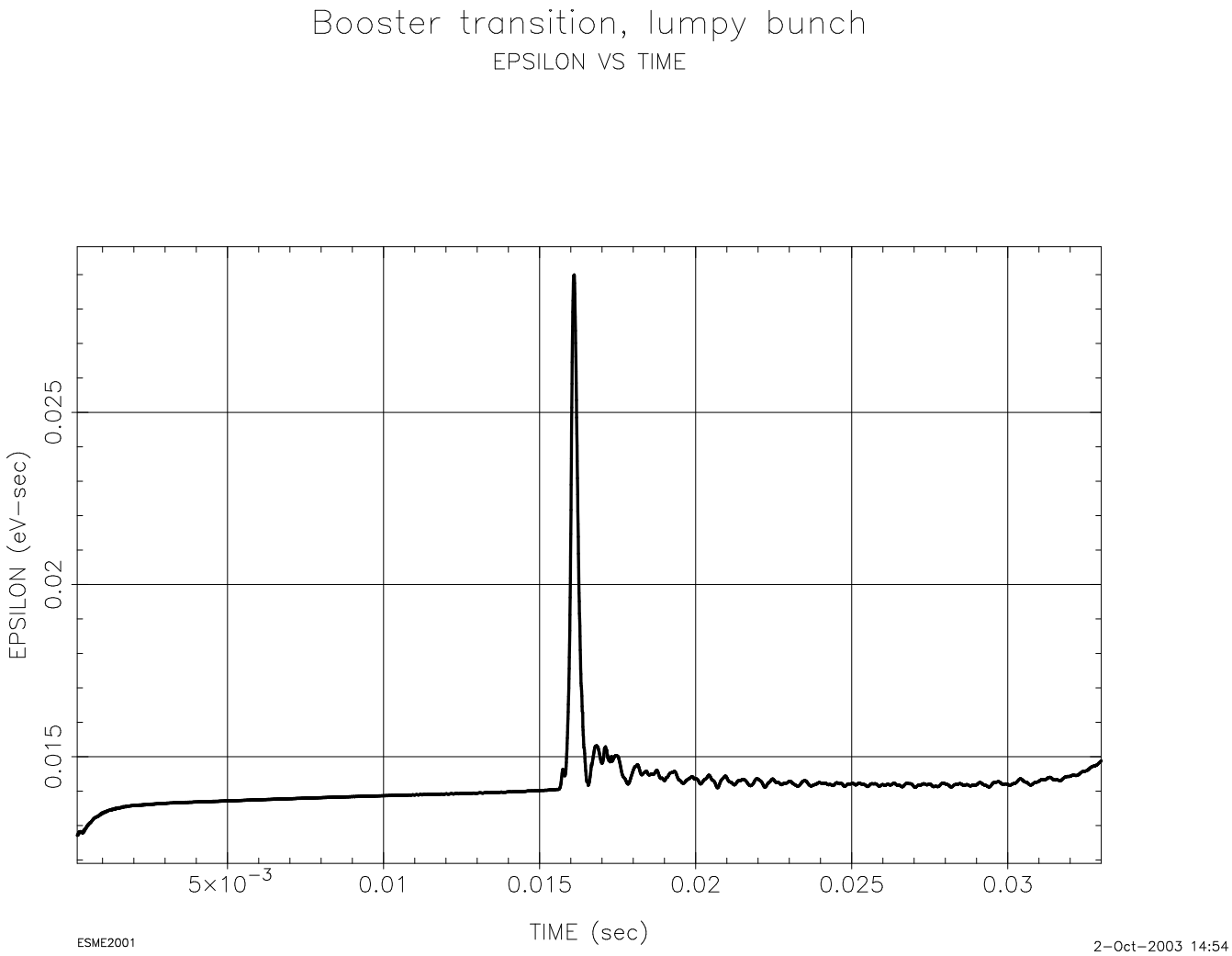
There were questions at the initial presentation about the actual emittance growth and the corrective effect of the present γ_T jump system. The following three plots answer some of these questions.



The emittance growth of the “lumpy bunch” crossing transition at 16.8(5) ms. The later, ragged part of the curve is not useful because particles are being lost from the bucket. The cause of the late loss is principally the failure to accommodate transition-related nonlinear single-particle effects on the bunch shape.



The emittance growth of a smooth elliptical bunch of the same initial emittance used in the preceeding case. The two plots are scarcely distinguishable, indicating that the microstructure present in the lumpy bunch has at most a minor effect on NMI.



The same lumpy bunch accelerated with a γ_T jump at 15.60 ms. The large jump in emittance at 15.6 ms is an artifact of increasing the number of macroparticles from $8.25 \cdot 10^6$ to $6.4 \cdot 10^8$ without informing the moments routine immediately of the change. Ignoring the meaningless spike, one finds both NMI and nonlinear effects practically absent in the vicinity of transition.